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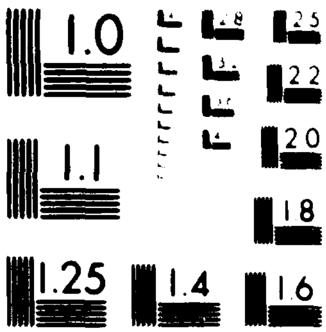
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NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

AN ANALYSIS OF ESTIMATED VERSUS ACTUAL DEVELOPMENT COSTS FOR AN ELECTRONICS STATE-OF-THE-ART (SOA) EXTENSION

by

RAYMOND E. BERUBE

December 1987

Thesis Advisor: W.R. Greer, Jr.

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This thesis is a case study that compares actual costs to estimated costs for a State-of-the-Art (SOA) extension. The Advanced Nuclear Gamma-Ray Spectrometer (ANGAS) program initiated by the Defense Advanced Research Project Office (DARPA) in conjunction with the Research and Development Division of Lockheed Missiles and Space Company (LMSC), Inc. is the subject of this case study. This thesis identifies: the original description of the technology extension; the methods used at Lockheed to develop SOA extension cost estimates; specific factors that helped and hindered accurate cost estimating and significant variances in cost and technological progress.

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An Analysis of Estimated Versus Actual Development Costs for an Electronics State-of-the-Art (SOA) Extension

by

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Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN MANAGEMENT

from the

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ABSTRACT

This thesis is a case study that compares actual costs to estimated costs for a State-of-the-Art (SOA) extension. The Advanced Nuclear Gamma-Ray Spectrometer (ANGAS) program initiated by the Defense Advanced Research Project Office (DARPA) in conjunction with the Research and Development Division of Lockheed Missiles and Space Company (LMSC), Inc. is the subject of this case study.

This thesis identifies: the original description of the technology extension; the methods used at Lockheed to develop SOA extension cost estimates; specific factors that helped and hindered accurate cost estimating and significant variances in cost and technological progress.

TABLE OF CONTENTS

I. INTRODUCTION

A. BACKGROUND

The development of new weapon systems for the Department of Defense (DOD) frequently requires State of-the-Art (SOA) extensions. The difficulty of estimating development and early production costs for new systems when SOA extensions are involved often leads to cost overruns. In fact, contractors' costs exceed project manager's estimates for new projects 60 percent of the time. [REF. 1 : p. 50-51.]

Prior research has not solved the problem of accurately estimating SOA extension costs. These development and production cost overruns make it difficult for DOD to accurately compare existing weapon technology with undeveloped technology.

Professor Willis R. Greer, Jr., Naval Postgraduate School, Monterey, California, in conjunction with the Naval Sea Systems Command (NAVSEA), is attempting to develop more reliable methodology for estimating the cost of extensions as applied to electronic systems. This thesis provides data to support that effort through the case study of an SOA extension.

B. OBJECTIVES

This thesis details the Advanced Nuclear Gamma-Ray Spectrometer (ANGAS) experiment program initiated by the Defense Advanced Research Projects Office in conjunction with the Research and Development Division of Lockheed Missiles and Space Company, Inc. The objectives are outlined below:

1. Identify the original description of the technology extension,
2. Document estimated development costs,

3. Describe the methods used to develop the cost estimates,

4. Compare actual cost data to estimated costs,

5. Analyze and measure any significant variances in cost or progress in technological development,

6. Identify specific factors that help or hinder accurate cost estimating.

C. RESEARCH QUESTIONS

Primary Research Question:

How do estimated development and production costs compare with actual costs for the ANGAS project?

Subsidiary Research Questions:

1. What methods and techniques were used to estimate development and production costs?
2. How was technological progress measured and evaluated?
3. What factors helped or hindered accurate cost estimating and accomplishment of stated SOA extension goals?

D. SCOPE LIMITATIONS AND ASSUMPTIONS

This thesis is a case study of the ANGAS project. The primary task is to obtain and analyze estimated and actual cost data, document cost estimation procedures for the ANGAS project and to evaluate generic cost estimating procedures used by Lockheed for SOA projects. The technological requirements of the ANGAS project are studied to measure the accomplishment of stated ANGAS technological goals.

The ANGAS project, an ongoing effort at Lockheed, is designed to produce one end unit to fly aboard a satellite. Thus, the cost data and estimation procedures presented in this paper are more applicable to development costs rather than to production costs. This is important because many SOA extensions, by their

nature, must be implemented through a substantial development effort. At the outset of many SOA development efforts, the end unit is more of an abstract idea than a detailed production specification.

> In the 1970's, system acquisitions programs were usually focused on specific technical approaches at the time of their initiation.
>
> Today a program is initiated after competent authority, the Program Decision Authority, approves a specific, formally stated mission need, based on Mission Area Analysis, submitted within the first Program Objectives Memorandum in which program funds are requested. [REF. 2 : p. 1-7.]

E. METHODOLOGY

The methodology used in this research is case study. Research trips to Lockheed included visits with the ANGAS contract administrator, principle investigator, senior cost estimator and several development engineers. These Lockheed personnel are located at facilities in Sunnyvale and Palo Alto, California. Lockheed personnel provided estimated costs, the associated cost estimation methods, actual costs incurred to date, a summary of progress, technological breakthroughs and specific factors that have helped and hindered the SOA extension effort.

The NAVPRO office, located in Sunnyvale, was visited numerous times to identify a suitable contract for study and to obtain relevant contract and cost data.

The ANGAS program manager was also interviewed to determine what the government hoped to achieve from the ANGAS project and how technological progress of that project is measured.

Background and research data were obtained through the Naval Postgraduate School library and its research services. Automated searches were conducted through the NPS library's DOD, NON-DOD and Defense Technical Information Center's files. Information obtained

through visits to Lockheed during the case study and related research material is contained in this thesis.

F. SUMMARY OF FINDINGS

Major findings of this thesis are summarized below:

1. There were no significant variances between estimated an actual costs to date. Spending was at a slightly lower rate than anticipated.

2. Like many research and development projects that are administered by a "level of effort contract", measurement and analysis of technological development is the primary gauge of effectiveness and progress.

3. SOA extensions, achieved by numerous smaller scale projects that incrementally extend the SOA, reduce the risk of both costs overruns and failure to achieve technological goals.

4. Personnel costs are the most significant cost factor in the development phase of SOA extensions.

5. Incremental funding of a DOD SOA project provides leverage to the government that can reduce cost overruns and achieve desired technological goals but tends to increase the length of time required for the development effort.

6. Currently available parametric models, used in private industry, could be applied to government use with proper historical data application and case-by-case analysis.

G. ORGANIZATION OF STUDY

Chapter II provides a background of the ANGAS project, an overview of cost estimation procedures used for ANGAS and a summary of cost estimation procedures and models used at Lockheed.

Chapter III details the methodology used in this thesis and present data.

Chapter IV analyzes the data in chapter III consistent with the stated objectives.

Chapter V states the conclusions drawn from this SOA extension case study.

II. BACKGROUND

A. PROJECT OVERVIEW

The Defense Advanced Research Projects Agency - 201 ANGAS program involves the design, test and fabrication of the ANGAS flight instrument and the performance of a long term flight demonstration in space. [REF. 3 : p. 3-2.]

The ANGAS project is designed to develop a gamma-ray spectrometer that will be carried into orbit by satillite. The spectrometer is designed to pasively detect radiation in space through an array of germanium sensors. The project will be completed when the designed spectrometer has been flown in space and the specified scientific results have been supplied to the government. The specific requirements of the ANGAS project are provided in the Statements of Work listed in Appendix B.

The ANGAS system required development of a large multi-element array of new, n-type, segmented germanium sensors. The design concepts represent a research and development effort which has never been performed before. This SOA extension in gamma-ray spectrometers incorporates the following new technologies:

1. Imaging collimator,
2. Cooled, radiation resistant n-type germanium sensors,
3. Anticoincidence shield,
4. Electronics subsystem which enables rapid onboard data analysis and microprocessor control,
5. Solid cryogen cooler.

The ANGAS program is being developed by Lockheed Space Sciences Laboratory which is part of the Lockheed Research and Development Division, the principle

research organization of the Lockheed Missiles and Space Corporation.

The government's program manager for ANGAS is LTCOL George P. Lasche, USA. He is in the Geophysical Sciences division at the Defense Advanced Research Projects Office, Arlington, VA. He described the ANGAS program goals as:

> An effort to develop new techniques and improve sensitivity and capability to record and passively detect radiation in space through a process of imaging with high energy resolution.[1]

A wide variety of potential DOD uses for ANGAS include its use as a means to verify arms treaty compliance from space.

B. OVERVIEW OF COST ESTIMATION PROCEDURES USED FOR ANGAS CONTRACT PROPOSALS

The principle method used by Lockheed Space Sciences Laboratory to determine the cost estimates for ANGAS contract proposals is a bottom-up, engineering estimate. To date approximately $4.96 million has been funded in two increments, in a "level of effort" type contract. The projected total funding for the entire ANGAS project will be approximately 17 million dollars.

Dr. George Nakano, Lockheed's principle investigator (project director / technical supervisor) for ANGAS explained that the ANGAS cost estimate:

> is a bottom-up estimate that is developed based on past experience of costs incurred developing similar satellite borne systems.[2]

The bottom-up estimating methodology used at Lockheed provides detailed functional and cost element estimates provided by the lowest competent level in the organization. The cost estimates developed for each

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[1] Information was obtained by telephone conversation on September 3, 1987.

[2] Information was obtained in an interview at Palo Alto, CA on September 4, 1987.

phase of the ANGAS contract were based on historical cost data, the requirements of the Work Breakdown Structure (WBS) and the Statement of Work (SOW) items listed in the Requests for Proposal (RFP).

Lockheed's contract pricing proposal for ANGAS contained the following summarized items. [REF. 3 : p. 2.2-2.3]

1. The overhead, general and administrative rates are applied as a percent times direct labor dollars. The rates were forecasts based on historical data and current projections.
2. Material requirements are identified, listed and priced by component or subsystem. These direct purchase items range from firm prices to estimates based on the accuracy that program requirements were defined.
3. Procurement burden is applied as a percent of the total estimated costs for material, purchased serices and subcontract and outside production costs. The rates are based on historical data and current projections.
4. Cost of money is an element of facilities capital. The rates are applied to the direct labor dollars associated with annual overhead and general andadministrative rates and to the base amount associated with the annual procurement burden. The cost of money rate used was 10.375 percent.
5. Air fare rates are averages of recent Lockheed ticket costs for tourist class to the designated cities. Per diem rates are based on historical data and current projections.
6. Direct labor hours, the most significant component of the ANGAS cost estimate, are based on a technical evaluation developed from a

detailed analysis of the program requirements. The basic labor rates are current average rates for direct labor pools, by skill categories that are used in the program. These rates are escalated by approved factors when appropriate to allow for future labor rate increases during the program.

All costs and applied rates were audited by the Defense Contract Audit Agency and negotiated with the cognizant government activity. Specific costs, rates and audit results will be discussed in Chapters III and IV.

Labor hour and cost estimates were based on previous satellite flight programs involving similar but much smaller gamma-ray sensor systems developed by Lockheed. The Defense Advanced Research Projects Agency 301 program although only one-forth the size of ANGAS and less technically complex was used in developing the ANGAS cost estimate.

C. SUMMARY OF COST ESTIMATION PROCEDURES AND MODELS USED BY LOCKHEED

The LMSC Estimating Systems Description (ESD) Manual provides company-wide guidance for estimating requirements for government or prime customer contracts.

The LMSC ESD Manual states:

> overall responsibility for the LMSC estimating definition, development, control and compliance is vested in the Vice-President, Finance. The Division Industrial Accountants report to the Vice-President Finance and are responsible for ensuring compliance with this document. [REF. 4 : p 1.3]

The following summary of cost estimation procedures and models is provided from information obtained from a presentation on SOA pricing by Mr. Ted Castro, Manager LMSC Estimating Systems, Mr. Donald H. Palmby, Manager LMSC Cost Modeling and Analysis, and Mr. Ken Peeler,

Chief Industrial Accountant LMSC Astronautics Division and the LMSC ESD Manual.

1. SOA Proposal Estimating Process

Figure 2-1, which follows this description of Lockheed's contract proposal estimating procedure provides a flow diagram of the process.[REF. 4 : p. 2.32 - 2.62]

The cost kick-off meeting establishes a schedule of deadlines for completion of cost inputs. Cost inputs and bases are generated for materials, direct labor and other direct costs.

The Federal Acquisition Requirements (FAR) directs DOD contractors to:

> provide a consolidated price summary of individual material quantities included in various tasks, orders or contract line items being proposed and the basis for pricing (vendor quotes, invoice prices, etc.). [REF 5. : 15.804-6]

Material requirements are broken down into three categories:

1. Subcontract estimates: obtained through formal, detailed RFPs or through estimation if sufficient time is not available to identify a subcontractor and obtain a price quote before Lockheed must respond to the government proposal. Lockheed is required to establish the reasonableness of any estimate through an independent cost analysis or technical basis.
2. Material estimates: includes prices for standard commercial items, raw materials, purchased parts and material usage costs. These material items are priced through historical data, supplier quotations and estimations.
3. Intra-Lockheed Work Transfer (IWT) Items: these material items are made at Lockheed. FAR requires that these items be transferred at

cost with an explanation of the pricing method used.

Once all material requirement costs are consolidated they are reviewed and additional analysis and justification is provided if needed or required by FAR. A consolidated price summary of all material requirements is then generated. Lockheed's final action for material costs is the application of material escalation rates if justified for a particular contract or contract phase.

Direct Labor cost estimates must:

> provide a time-phased (e.g. monthly, quarterly,etc.) breakdown of labor hours, rates and cost by appropriate category, and furnish bases for estimates. [REF. 5 : FAR 15.804-6]

Direct labor estimates are usually expressed by Lockheed in labor hours, identified directly to research, design, production or other project objective. To justify direct labor estimates, the requirements of an SOA extension RFP are broken down into tasks consistent with SOW requirements or WBS element. The two basic methods used to provide a basis of estimate (BOE) for hours quoted are:

1. Historical or similar to data: this is the preferred BOE for quoting direct labor hours. Similar programs are used to identify tasks that are equivalent to tasks to be performed in the proposed contract. Adjustments or applied factors are often used to calibrate historical data. Justification of adjustments or factors is required by FAR.
2. Engineering estimates: used when no historical or similar to data is available. Tasks are broken down to the lowest level of detail.

Use of estimating standards is a direct labor estimating method which relates production costs to specific characteristics of a product, such as weight,

size or composition.

> Cost estimating standards must be applied consistently based on verified, uniformly correlated data expressed in the same unit of measure.[REF. 4 : p. 2.60]

A learning curve, which predicts the extent to which experience in performing a task will decrease the labor time needed to perform that task, is then applied by Lockheed to all labor estimates. The LMSC labor cost accumulation system is the data base used to develop learning curves. Curve selection and slope definition depend on a number of factors, including:

1. how the data has been accumulated (by lot or unit),
2. whether the item is a follow-on to an existing production run or an estimate based on a similar item,
3. if a production break, change in design technology or factory method has occurred, and
4. customer specification of the methodology, [REF. 4 : p 2.61]

Once total labor hour estimates are compiled and reviewed Lockheed direct labor hour rates are applied to the labor hours. The estimation of "other direct costs" and BOE is the final major cost category that must be derived for an SOA extension price quote. Other direct costs include:

> travel, overtime premiums, allocated prime cost (APC)/pooled work orders, monitored line parts APC, relocation expenses and foreign field service bonuses.[REF. 6 : p. 2-62].

Other direct costs are usually based on historical or direct estimating procedures. All estimates for materials, direct labor and other direct costs form the initial cost proposal which is now reviewed and approved or disapproved. If approved management price review and negotiation and sometimes best and final offer steps follow.

2. Bottom - Up Cost Estimating Method

Lockheed uses a multiple estimating approach. When detailed task definition is available a bottom - up / engineering estimate is prepared by the cognizant division(s). These bottom - up estimates provide:

1. High degree of accuracy and traceability,
2. Cost breakdowns to the lowest levels of the WBS,
3. Based on historical data.

The primary disadvantages of a bottom - up cost estimate for an SOA extension effort are:

1. Dependence on detailed design specifications which do not usually exist during early phases of SOA extension projects,
2. Expensive and time consuming,
3. Cannot be used as the sole costing method
4. Trade - off analysis is not easily evaluated.

Although many SOA extensions do not initially provide detailed design specifications, bottom - up cost estimating is sometimes still used by Lockheed. Estimates are based on the experience gained by individual engineers and technicians from developing systems or components that used existing SOA technology. Many of the SOA extension contracts awarded to Lockheed are an extension of technologies and systems developed previously by Lockheed. Bottom - up SOA extension cost estimates are reconciled with experience and computer cost models.

Various computer models are used in SOA cost estimating by Lockheed to establish "price targets", provide "sanity checks" and reconcile other cost estimations.

3. Parametric Cost Models

Lockheed uses the RCA PRICE Hardware (H) parametric cost model early in the development or

concept exploration stages of an SOA extension.

The PRICE model contains thousands of mathematical equations relating the input variables to cost. Each specific set of input parameters uniquely defines the hardware for cost modeling. The resultant cost output is determined from the mathematical equations alone. PRICE does not perform the function of a table look-up model.

PRICE has been designed to estimate costs with a minimal amount of hardware information. This feature makes it a legitimate tool for cost estimation of programs in concept stage of development,since the model uses its internally generated values for any missing input variables in order toestimate cost. Of course,it is always preferable for the PRICE user to supply the inputs, when their values are known. In this way, the statistical uncertainty is reduced. [REF. 6 : p. 7]

Lockheed applies the PRICE H model when "key representative system characteristics are known."[3]

PRICE H also identifies cost drivers and quickly and economically evaluates SOA extension trade-off and schedule analysis.

The major disadvantages of the PRICE H model as noted by LMSC's senior cost estimating managers are:

1. Not based on actual history,
2. Algorithms need to be adjusted for different projects, divisions and acquisition environments.

PRICE H relies on input of a subassembly or higher level unit's active electronic weight and mechanical/structural weight as the most critical cost and schedule factors. The accuracy of the PRICE output is directly related to the accuracy of the weights input.

Input characteristics of the PRICE H model which enhances its value as an SOA extension cost estimation model are:

1. Inputs consider the lead time necessary for set-up, parts procurement and redesign. This is significant for most SOA extensions.

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[3] Information obtained from LMSC SOA cost presentation, September 24, 1987, Sunnyvale, CA.

2. The degree of new design and complexity of development engineering tasks is included.

3. The operational environment in which the system is to be used is evaluated in cost estimates. SOA extensions such as the ANGAS project are designed to be used in a new operational environment, outside the earth's atmosphere.

4. Type and manufacturing complexity of the electronics within the system or component is evaluated by the model. New electronics design is often a significant factor of SOA extension costs.

5. The model also evaluates technological improvement, year of technology and technological delay or lags. These inputs are often SOA extension cost drivers.

Illustration 2-1 is a sample output of a PRICE H run provided by LMSC Cost Modeling and Analysis Manager. The output has been broken down into six sections. The following general output descriptions are summarized from the PRICE Executive Handbook [REF. 7 : p. 20]. Relevant SOA extension output data is also highlighted.

Section 1: identifies time of the run, the name of the item, general information about the item, the recurring unit production cost and monthly production rates. Illus. 2-1 identifies the item as a pyro-kit, to be produced in a quantity of one. The unit weight was input at 7.96 pounds, the unit volume was .26 cubic feet and mode two designates the item as a mechanical item with no electronic elements. The quantity / next higher assembly designator is a one which determines the number of units required to be integrated and tested at the next higher assembly level.

Section 2: lists program costs in engineering and manufacturing subtotals. Illustration 2-1 indicates only production costs of 1008 dollars. Development costs are blank, indicating that no development costs are required. Many SOA extensions require significant development costs. The ability of PRICE H to output development and production costs separately is useful in analysis of technological alternatives. Illus. 2-1 lists engineering costs of $504. These costs are composed of drafting costs of $46., design costs of $250., project management costs of $148. and data costs of $60. Manufacturing costs total $505. These costs are composed of production costs of $453. and tools and test equipment costs of $52. Total engineering and manufacturing costs

equal $1008.

Section 3: provides output useful for analysis of the inputs with known standards. Density, engineering changes and mean time between failures values in Illus. 2-1 are followed by an asterisk. This indicates that these input values were not known and calculated by the model. Many inputs required to estimate the costs of an SOA extension are not available during the early phases of development. The ability of the PRICE H model to derive output and then provide missing input is ideal for SOA extensions during early phases. Illus. 2-1 shows mechanical design factors that were input for the run. The manufacturing complexity of 10.42 is an empiricaly derived value that represents the product's producibility which is a function of material type, finished density and fabrication methods. The mechanical integration level of .7 represents the level of mechanical integration and test. This factor describes the level of effort required for the integration of mechanical equipment in the next higher assembly. The platform input of 2.2 designates the intended operating environment. An input of 2.0 or more represents unmanned or manned space operations. The year of technology, 1985, has been calculated by the program. The reliability factor of 1.0 is a multiplier used to deviate the mean time between failure value which has been calculated by the model.

Section 4: outputs development and/or production schedule information. Illus. 2-1 indicates that the dates for completion of the first item and overall completion were not known before the run. The model provides valuable schedule information which is often difficult to determine for SOA extensions.

Section 5: provides additional, in-depth cost output. The model again provides previously unknown information which would be valuable for SOA extension estimating. First unit production costs are $452.17, amortized unit costs are $1008.30, the production tooling cost factor is 1.0 and the unit learning curve is 86.4 percent. The production cost multiplier of 1.20 is a multiplying factor used to include mock-ups for general and administrative and fee or profit in the production cost outputs.

Section 6: one of the most useful outputs of the PRICE H model is the cost uncertainty measure. Illus. 2-1 provides a cost range of 954 to 1046 dollars. SOA extension development and production costs inherently contain a high level of uncertainty due to the technical innovation and engineering complexity.

4. The Lockheed STAR Cost Estimating Model

Lockheed's STAR cost estimation model combines the characteristics of a similar-to model and an associated model. A similar-to methodology uses historical cost data from tasks or equipment similar to the equipment under evaluation. A high degree of accuracy and cost breakdowns to the subsystem or box level (WBS level 3 or 4) is provided.

The associated program methodology uses total annual costs from technically representative projects that have been adjusted by economic and complexity factors.

The basis of the STAR model is the detailed historical database that has been developed over a 20 year period. This data base represents actual production and development cost experience, rather than success oriented, or tailored data.

The STAR model is made up of three distinct estimating models with separate data bases for each. A flight hardware cost estimator, a ground hardware cost estimator and a software cost estimator. The individual models use an algorithm designed for its particular line of business. The software cost estimator works with a software size estimator that calculates lines of code by functional application. The three models can be used in an integrated manner to derive a total system cost.

Minimum inputs include: program hardware / software lists, a master schedule and the year dollars required. Critical SOA extension estimating factors such as: design complexity, escalation of costs, and quantity are incorporated in the STAR model.

The primary advantage of the STAR model compared to the PRICE H model is that output is derived

from actual or historical costs. STAR also allows updating of costs as a project progresses and tradeoff and "what if analysis".

The STAR model contains a program loader that pulls the required type of data from the data base. The FILGEN pulls analogous cost items from the data base. Each item on the program hardware list is coded with a box status, box type and engineering status.

Box status codes are either: make (m), buy (b) or government furnished equipment (g).

Box type codes are either: development (d), qualification (q) or production (p).

Engineering status codes are either: new (n), modified (m), existing (e) or production (p).

Each item on the program hardware list is also assigned input values for: quality, management effort, design engineering required, systems engineering required, software engineering effort required, the manufacturing complexity, test requirements and product assurance.

The model now makes a cost run, the Lockheed labor rates are the default labor rate values. Appendix C[4] provides sample output for a subsystem program hardware list.

Final output includes: total hours, dollar value for the labor hours, material costs in dollars and total dollar value for each item on the subsystem hardware list. The final total price is obtained from analogous, historical cost data. If any of seven input values were not initially known the total cost is normalized and reallocated back to the missing boxes.

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[4] APPENDIX C is not part of the unlimited distribution of this thesis. Individuals within DOD may obtain a copy of APPENDIX C from Professor Willis R. Greer, Jr., Naval Postgraduate School, Monterey, California.

The STAR model is an ideal tool for Lockheed to use to estimate SOA extension costs. The data base is retrievable by line item or box level, which enables composite data from even classified projects to be included as unclassified useable data.

If a particular line item on the hardware parts requirement list is going to be subcontracted or purchased directly, the program allows these known costs to be entered. Otherwise a data base is selected which matches the functional and characteristic qualities of the item. The default learning curve value is 95 percent.

The output of the STAR model is designed to aid SOA cost analysis. Output can be formatted to provide: development/non-recurring costs and production / recurring costs. Appendix C provides sample output in this format and an example of output in WBS reference number sequence.

The accurate, uniform measurement and correlation of historical data into box level or component factor enables extremely precise SOA extension cost estimations by the STAR model once parts requirements are well defined.

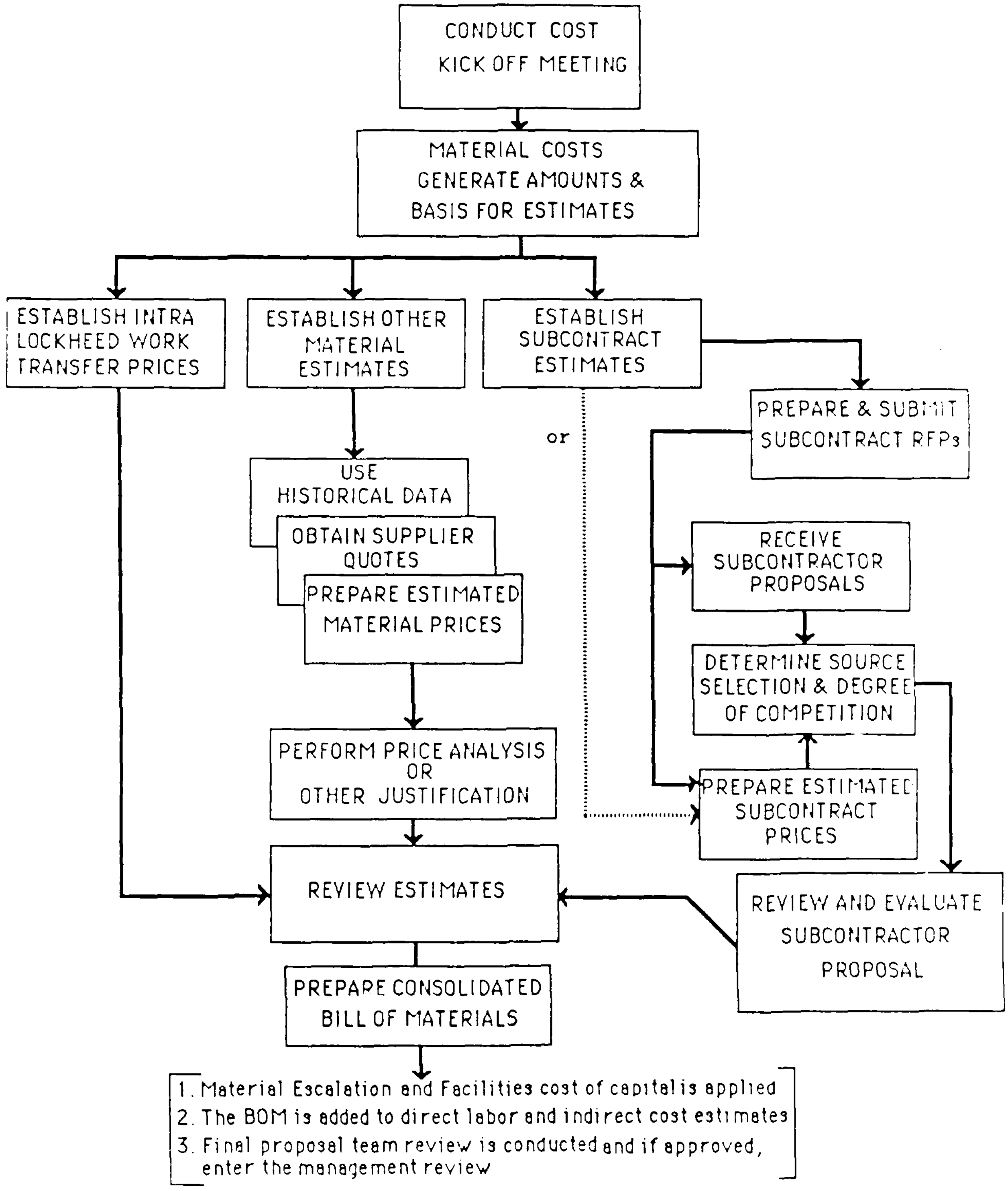


Figure 2-1 Cost Estimation Process

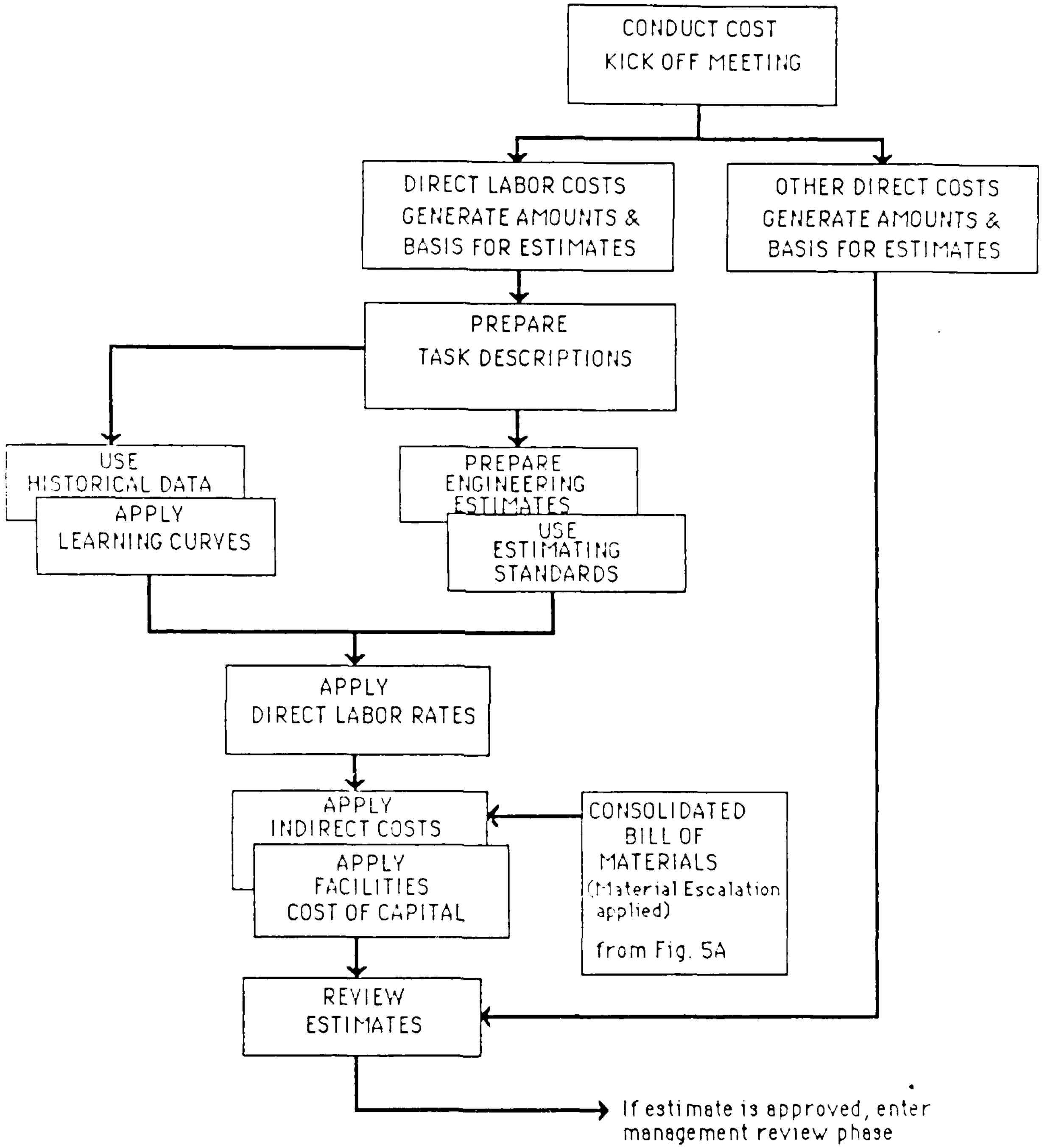


Figure 2-1 (Continued)

ILLUSTRATION 2-1

I.

INPUT FILENAME: EX 24 SEPT 87 16:56
GLOBAL FILENAME: LMSCGL01

PYRO KIT

PRODUCTION QUANTITY 1

UNIT WEIGHT	7.96	MODE	2
UNIT VOLUME	0.26	QUANTITY/NHA	1
UNIT PRODUCTION COST	452.67		
MONTHLY PRODUCTION RATE	0.00		

II.

PROGRAM COST ($1000)	DEVELOPMENT	PRODUCTION	TOTAL COST
ENGINEERING			
Drafting	-	46	46
Design	-	250	250
Systems	-	-	-
Project Mgmt	-	148	148
Data	-	60	60
Subtotal(ENG)	-	504	504
MANUFACTURING			
Production	-	453	453
Prototype	-	-	-
Tool-Test Eq	-	52	52
Subtotal(MFG)		505	505
TOTAL COST		1008	1008

III.

DESIGN FACTORS	MECHANICAL	PRODUCT DESCRIPTORS	
Weight	7.960	Platform	2.200
Density	30.038*	Year of Tech.	1985
Mfg. Complexity	10.422	Reliability Fac.	1.0
Engineering Change	0.033*	MTBF(Field)	21971*
Integration Level	0.700		

IV.

SCHEDULE	START	FIRST ITEM	FINISH
Production	Jan 85 (19)	Jul 86* (0)	Jul 86* (19)

ILLUSTRATION 2-1 (Continued)

V.

SUPPLEMENTAL INFORMATION

Economic Base	185	Tooling and Process Factors	
Escalation	0.00	Production Tooling	1.00*
T-1 Cost	452.17*	Rate Tooling	0
Amor Unit Cost	1008.30*	Price Info Factor	0.950
Prod Cost Mult	1.20	Unit Learning Curve	0.864

VI.

COST RANGES	DEVELOPMENT	PRODUCTION	TOTAL COST
From	-	954	954
Center	-	1008	1008
To	-	1046	1046

III. METHODOLOGY AND DATA

A. INTRODUCTION

This chapter describes the methodology of the thesis and presents data that was collected during the study. The methodology section is divided into two subsections, data collection and data analysis.

Data includes: estimated costs submitted by Lockheed in the ANGAS contract proposals; Defense Contracts Audit Agency (DCAA) audits of the ANGAS contract proposals; costs questioned in the DCAA audits; final negotiated costs with justifications; actual costs incurred at different stages of the contract; statement of work items; a listing of major milestones.

B. METHODOLOGY

1. Data Collection

The methodology used in this research is case study. An information search was conducted to obtain background data. Automated searches were conducted through the Naval Postgraduate School library's DOD, NON-DOD and Defense Technical Information Center's files. The following literature provides information on SOA extensions, development and production cost estimation issues and a background that will enhance understanding of the issues in this case study. Literature that is pertinent to data analysis methodology will be presented later in this chapter.

Captain Helmut W.F. Scheel, USAF, in his master's thesis [REF. 1:p. 1-91], studied the methods, techniques and objectives used in estimating costs for exploratory development projects by Air Force Research and Development Laboratories. He also attempted to

identify factors which contribute to the variance between project manager's cost estimates and contractor's proposal costs. Captain H. Scheel surveyed 45 government project managers to determine cost estimating techniques. Important conclusions of his study include:

1. 77.8 percent of the program managers used historical data for general cost estimating.
2. 82.2 percent of the program managers used historical data and experience/judgment to estimate labor costs and manpower requirements.
3. Low cost estimates were sometimes made because of limited funds available for a specific project.
4. The major variance factor attributable to the bidders was errors in estimation as a result of misinterpretation of the Statement of Work (SOW).
5. Contractors can sometimes propose a different level of effort than specified in an SOA extension due to technical insight and capabilities known only by the contractor.
6. Establishment of a computerized system with standardized software would provide a data bank that would enable more accurate cost estimation analysis within the government.
7. Most project managers do not accurately estimate costs for new projects. The majority underestimate by 30 percent or less, although some underestimate by as much as 200 percent. [REF. 1:p. 33, 36, 41, 51, 67, 92-96]

The ANGAS project, like most SOA extension efforts, requires a long research and development (R&D) period. To accurately estimate and evaluate proposed contractor costs an understanding of long-range corporate R&D planning is useful. Ward C. Lowe framed the process into seven significant steps:

1. Specify as clearly as possible the basic technological objectives which are of primary interest. These may be stated broadly at the beginning but must eventually be broken down into particular areas.
2. Identify the goals toward which the company is working, which ideally are set forth in the corporate and the research objectives.
3. In keeping with the preceding two factors, seriously and imaginatively consider all possible results which may be achieved if the research efforts are successful.

4. Rank the hypothetical capabilities of the research efforts as determined in the preceding step, in terms of their potential contribution to the achievement of specific goals. The ranking should achieve the corporate or the research objectives.

5. Outline the principle technological steps which are required to achieve the hypothetical research results listed in the preceding step. Such an outline should uncover the more significant gaps in existing knowledge.

6. Select the small number of high-value research results, as determined previously, which have reasonably well-specified steps and a minimum number of knowledge gaps. Give these results further examination and consideration for full-scale research efforts.

7. Remain alert to any developments that could significantly change the value ratings used in the preceding steps. When research breakthroughs fill in missing knowledge gaps, the process should be repeated. [REF. 8:p. 62-63]

The above steps are also useful for government program managers when defining the technological goals of SOA extension projects and drafting the SOW. Accomplishment of SOW items during the development phase of an SOA extension contract may be the primary measurement tool for evaluating technological progress.

The bottom-up, parametric and similar-to-cost estimating models described in Chapter II are the most widely used cost estimating methods. References 4, 6, and 7 provide information for further study.

It was time consuming and difficult to identify a company willing to cooperate in a case study which offered an SOA extension project useful for analysis. Several Marketing and Research and Development Directors were contacted by telephone to determine interest in and suitability for study.

Companies initially contacted included GTE Inc.; National Semi-Conductor Inc.; Fairchild Inc.; Advanced Microcircuit Devices Inc.; Cypress Electronics Inc.; Acrian Inc.; Hewlett Packard Inc.; Harris

Microwave Inc; Intel Corp. Inc.; Litton Industries Inc.; and Eaton Semiconductors Inc.

Company responses ranged from "not interested" to enthusiastic requests for additional information about the research effort. Companies expressing an interest in aiding the research effort were then evaluated on their ability to provide viable projects for study. Three other Naval Postgraduate School students had selected SOA extension case studies for their theses. All of us worked as a team to identify appropriate firms. These efforts resulted in the selection of GTE Inc. and Litton Industries, Inc., as candidates for study by two other graduate students.

LCDR. Fred Voellm, SC, USN, of the Navy Procurement Office located at LMSC, was contacted for assistance in identifying a government contract administered by his office for an SOA extension that could be studied. LCDR. Voellm produced a list of contracts that were considered high technology and potential candidates for study.

Individual contracts were evaluated on the degree of new technologies and SOA extension, the availability of initial and actual cost data and the stage of completion of the contract.

The ANGAS experiment program initiated by the Defense Advanced Research Projects Office in conjunction with the Research and Development Division of LMSC was selected because it combined numerous SOA technological extensions into a design that was unique and required operation in space. Selection of the ANGAS project, which is still in early research and design stages, provided an opportunity to study development costs and how technological progress is evaluated.

Mr. Don Dorsett, LMSC's ANGAS contract administrator, was visited numerous times to obtain background and cost data. The ANGAS "Weekly Financial Status Report" and "Work in Process Ledger by Work Order" provided actual current costs and spending rates. A summary of this data will be presented in the data section of this chapter. Mr. Dorsett also discussed the significant technological and SOA extension characteristics of the ANGAS project. These are listed in Chapter II.

LTCOL. George P. Lasche, USA, Geophysical Sciences Division, Defense Advanced Research Projects Office, Arlington, VA, is the government's program manager for the ANGAS program. LTCOL Lasche, USA, was interviewed by telephone. The project's technological objectives, goals, potential applications, program status and evaluation techniques used to analyze proposed contractor costs will be presented in the data section of this chapter.

The government program manager for the ANGAS program authorized access to the principle investigator at the Lockheed Space Sciences Laboratory in Palo Alto, CA, Dr. George Nakano. Lockheed's principle investigator for the ANGAS project is responsible for technical supervision and overall project direction. Dr. Nakano was interviewed by telephone and visited at the Space Sciences Laboratory. His description of the ANGAS cost estimation effort, accomplishment of technological goals, spending status, problem areas and significant SOA extension achievements will be presented in the data section of this chapter, Appendix B and Chapter IV.

Cost estimation procedures used by Lockheed were obtained from Lockheed's Estimating Systems Description Manual and from a presentation on SOA

pricing by Mr. Ted Castro, Manager of Lockheed's Estimating Systems; Mr. Donald H. Palmby, Manager of Lockheed's Cost Modeling and Analysis; and Mr. Ken Peeler, Chief Industrial Accountant of Lockheed's Astronautics Division.

Information and characteristics of bottom-up cost estimating, parametric cost models and Lockheed's internally developed STAR cost estimation were obtained. Input parameters and output data were obtained for sample SOA extension component cost estimates using the parametric and STAR cost estimation models. This information was detailed in Chapter II.

2. Data Analysis

The estimated ANGAS development costs as provided in Lockheed's contract proposal and modified after government audit and negotiation are compared to actual reported costs. Differences and trends in specific cost categories are analyzed. Overall spending rates are compared with anticipated spending. The results of the data analysis are presented in Chapter IV.

Significant characteristics of Lockheed's cost estimating methods and models that are potentially useful in aiding better estimation of SOA extension projects by the government are also recorded in Chapter IV.

The specific methodology that will be used in the cost analysis will closely follow Dearden's simple variance analysis as detailed in Cost and Budget Analysis. Actual costs will be obtained from the ANGAS "Weekly Financial Status Report" and compared with the estimated or "budgeted costs" in a variance matrix format.

Budgeted costs will define the planned expenditure for work scheduled for accomplishment

during a specific phase of the contract. The budgeted cost from work scheduled (BCWS) for a level of effort contract, like the ANGAS contract, "is based on expected expenditures by tasks to be completed." [REF. 9:p. 6]

A determination of the degree of completion for stated technological goals and task completion is provided in Chapter IV. Information obtained from the government's program manager and the ANGAS principle investigator about the status of the SOW items will be the basis for establishing task and technological progress. The reasons why the program manager was able to :

> specify as clearly as possible the basic technological objectives which are of primary interest [REF. 8:p. 62]

will also be discussed in Chapter IV.

C. DATA

1. Introduction

The Research and Development Division of LMSC, Palo Alto, CA, has been funded through an incremental cost-plus-fixed-fee contract to develop the ANGAS. The major milestones are presented in Appendix B.

> In a cost-plus-fixed-fee contract, the government pays allowable cost and a fixed fee. Fixed fee does not vary with actual costs. Provides minimum incentive for contractors to control costs. Completion requires contractor to deliver end product. Requires specified level of effort over stated period of time. Used most widely for research, preliminary exploration or study. [REF. 10:p. 49]

The following information details ANGAS funding to date:

PERIOD	EST. COST	FIXED FEE	COST PLUS FEE
1	$ 1,281,655	$ 68,345	$ 1,350,000
2	$ 3,392,620	$ 192,843	$ 3,585,463
TOTALS	$ 4,674,275	$ 261,188	$ 4,935,463

LMSC submitted a contract proposal on November 26, 1985, after the first incremental funding had been approved, that covered a 78 month period commencing April 1, 1986 through completion. The government choose not to allocate funds for this entire 6 1/2 year period and has incrementally funded the project. The contractor's proposed cost for completion of ANGAS was $16,589,398.00 (CPFF). Appendix B contains the SOW items from the two incrementally funded contracts and the unfunded proposed completion contract.

D. ESTIMATED COSTS FOR FIRST CONTRACT PHASE

LMSC, Research and Development Division submitted the following breakdown of proposed costs for the initial ANGAS contract:

PRICE BREAKDOWN

DESCRIPTION	TOTALS
LABOR HOURS	14,688
LABOR DOLLARS	$ 319,630
OVERHEAD	506,192
G & A EXPENSES	134,942
MATERIALS	110,793
SUBCONTRACT	146,700
PROCUREMENT BURDEN	9,012
TRAVEL	16,064
SUB. COSTS	$1,243,333
COST OF MONEY	38,322
TOTAL COST	$1,281,655
FIXED	99,647
TOTAL CPFF	$1,381,122

The individual cost element totals were developed as follows:

1. Direct Labor - direct labor hours are based on a technical evaluation developed from detailed analysis of the program requirements. The labor rates are current averages for direct labor pools, by skill categories.

	HOURS	RATE	AMOUNT
DESIGN ENGINEER	2,324	$18.31	$42,546
DESIGN ENGINEER - SENIOR	2,656	$22.08	$58,638
DESIGN SPECIALIST	664	$26.13	$17,350
ENGINEER/SCIENTIFIC CLERICAL AID	179	$12.46	$ 2,230
LABORATORY ANALYST - RESEARCH	1,162	$16.67	$19,376
RESEARCH ENGINEER	1,148	$18.87	$21,661
SCIENTIST, SENIOR	1,328	$17.89	$23,755
SCIENTIST - RESEARCH	2,656	$24.24	$64,391
STAFF ENGINEER	621	$28.07	$17,430
STAFF SCIENTIST	1,771	$28.01	$49,608
TECHNICAL PUBLICATIONS	179	$14.78	$ 2,645
TOTAL DIRECT LABOR	14,688	$21.76	$319,630

2. Overhead rates are applied as a percent times direct labor dollars. The rates used for 1985 and 1986 were 1.592 and 1.560, respectively. These rates apply to R & D projects.

		BASE	RATE	AMOUNT
OVERHEAD	1985	$236,523	1.592	$376 545
	1986	$83,107	1.560	$129,647
TOTAL OVERHEAD		$319,630		$506,192

3. General and Administrative Expenses are also applied as a percent times direct labor dollars. The rate used for 1985 and 1986 were .424 and .417, respectively.

		BASE	RATE	AMOUNT
G & A EXPENSES	1985	$236,523	0.424	$100,286
	1986	$ 83,107	0.417	$ 34,656
TOTAL G & A EXPENSES		$319,630		$134,942

4. Material requirements were listed, identified and priced by component. Costs of purchased services are also included in this cost element.

MATERIAL	1985	$51,547
PURCHASED SERV.	1985	$59,246
TOTAL MATERIALS		$110,793

5. Subcontract cost estimates are based on actual price quotes received from the subcontractors in response to a RFP. Subcontract costs for 1985 were estimated at $146,700.

6. Procurement burden is applied at the rate of .035 of the total estimated costs for materials, purchased services and subcontract costs. The rate is developed from historical data.

		BASE	RATE	AMOUNT
	1985	257,493	0.035	$9,012
TOTAL PROCUREMENT BURDEN				$9,012

7. Travel - per diem rates are based on historical data and air fare costs are based on tourist

class rates. Travel reflects anticipated project requirements.

		QTY	RATE	AMOUNT
AIR FARE				
ALBUQUERQUE 2 TRIPS OF 2 MEN FOR 3 DAYS TECH MEETING	1985	4	$ 193	772
DENVER 2 TRIPS OF 2 MEN FOR 3 DAYS INTEGRATION COORDINATION	1985	4	$ 325	1,300
LOS ANGELES/BURBANK 3 TRIPS OF 2 MEN FOR 1 DAY FLT. COORD. MEETING	1985	4	$ 145	870
WASHINGTON/BALTIMORE 6 TRIPS OF 2 MEN FOR 3 DAYS VENDOR & CUST COORD.	1985	12	$ 556	6,672
PER DIEM				
ONE DAY TRIPS		6	$ 45	270
WEST COAST TRIPS		24	$ 91	2,184
EAST COAST TRIPS		36	$ 111	3,966
	TOTAL TRAVEL		$	16,064

8. Cost of money is an element of facilities capital. Rates are applied to direct labor dollars, general and overhead base and the procurement burden base.

		BASE	RATE	AMOUNT
DEVELOPMENT-LMSC	1985	$ 236,523	0.10310	$ 24,386
	1986	$ 83,107	0.12283	$ 10,208
G & A EXPENSES	1985	$ 236,523	0.01055	$ 2,495
	1986	$ 83,107	0.01254	$ 1,042
PROCUREMENT BURD	1985	$ 257,493	0.00074	$ 191
TOTAL COST OF MONEY				$ 38,322

The total of the cost elements is $1,281,655. Lockheed submitted the contract proposal with a fixed fee of $99,467, 8 percent of costs. The total CPFF requested by Lockheed for the first phase of the contract was $1,381,122.

E. DCAA AUDIT REVIEW

Lockheed's cost proposal was audited by DCAA, Sunnyvale, CA. The results summarized below are set forth in audit report 7481 - 5G 210091, dated 5 June 1985.

COST ELEMENT	CONTRACTORS PROPOSAL	QUESTIONED COSTS
SUBCONTRACTS	$ 146,700	$ 25,379
PURCHASED SERVICES	59,246	59,246
MATERIAL	51,547	51,547
PROCUREMENT BURDEN	9,012	4,766
	$ 266,505	$ 140,938

DCAA questioned the subcontract costs of $ 146,700 because a cost or price analysis had not been completed by LMSC. Cost or price analysis for subcontracts is required by FAR 15.806. DCAA, therefore, applied a 17.3 percent negotiation reduction factor to the proposed costs. The 17.3 percent factor is based on DCAA evaluation of subcontract history in the Astronautics and Space Systems Division.

The purchased services of $ 59,246 and material of $51,547 were questioned because LMSC did not provide any data in support of the proposed costs.

The procurement burden was reduced due to the above questioned costs and the reduced procurement burden base.

QUESTIONED BASE COSTS	$136,172
PROPOSED RATE	X 3.5%
TOTAL QUESTIONED	$ 4,766

1. Summary Of Cost And Fee Negotiations

LMSC submitted an SF 1411 with supporting documentation to justify the questioned subcontractor costs. This documentation was reviewed and approved by the negotiator and scientific officer.

LMSC also provided a detailed breakdown of the questioned costs for purchased services and materials which was approved by the government. These price breakdowns were based on past experience on similar projects, such as project Winkler, catalog prices and vendor quotes.

All questioned costs were reviewed and accepted after negotiation. LMSC had requested a fee of 8

percent of costs ($99,467), the government's fee objective was 4.2 percent. As a result of negotiations, the settled fee was 5.5 percent ($68,345). The final estimated costs for the first phase of the ANGAS project was:

ESTIMATED COST	FIXED FEE	TCFF
$1,281,000	$ 68,345	$1,350,000

F. ESTIMATED COSTS FOR SECOND CONTRACT PHASE

LMSC submitted a cost proposal dated 26 November 1985 in the amount of $16,589,398, covering a period of performance of six and one-half years. Audit report 7481 - 6G210136 conducted by DCAA, Sunnyvale, CA, questioned portions of every item in the budget. LMSC was unable to substantiate its cost estimates to the satisfaction of the government. LMSC was unable to accurately project costs six years into the future for a program still in the design phase.

It was decided to contract only for the final design and sensor shield evaluation of the ANGAS project. The SOW is illustrated in Appendix B. LMSC proposed a cost of $ 3,694,580. The costs were broken down into the same cost elements as the first contract detailed earlier in this chapter.

1. DCAA Audit Review And Negotiation

The following proposed costs were questioned and negotiated:

1. Labor Rates - LMSC used an escalation factor of 4.5 percent. Due to the government ceiling on salary escalation, LMSC was instructed to recompute labor rates using a 3.5 percent escalation.

CATEGORY	PROPOSED RATE	NEGOTIATED RATE	TOTAL HOURS
TECHNICAL SPECIALIST	$ 24.66	$ 24.42	10,210
TECHNICAL STAFF	$ 30.64	$ 30.35	6,512
TECHNICAL SENIOR	$ 21.45	$ 21.24	10,460
TECHNICAL ENGINEER	$ 17.91	$ 17.74	9,559
TECHNICAL SUPPORT	$ 13.60	$ 13.47	812
LABORATORY SERVICES	$ 17.27	$ 17.11	2,006
TECHNICAL PUBS.	$ 15.94	$ 15.78	493

2. Fee Negotiation - LMSC requested a fee of 9 percent of costs, exclusive of cost-of-money. The government's fee objective was 4.9 percent. A fee of 5.8 percent, exclusive of cost-of-money, was negotiated.

2. Summary Of Estimated Costs For The Second Contract Award

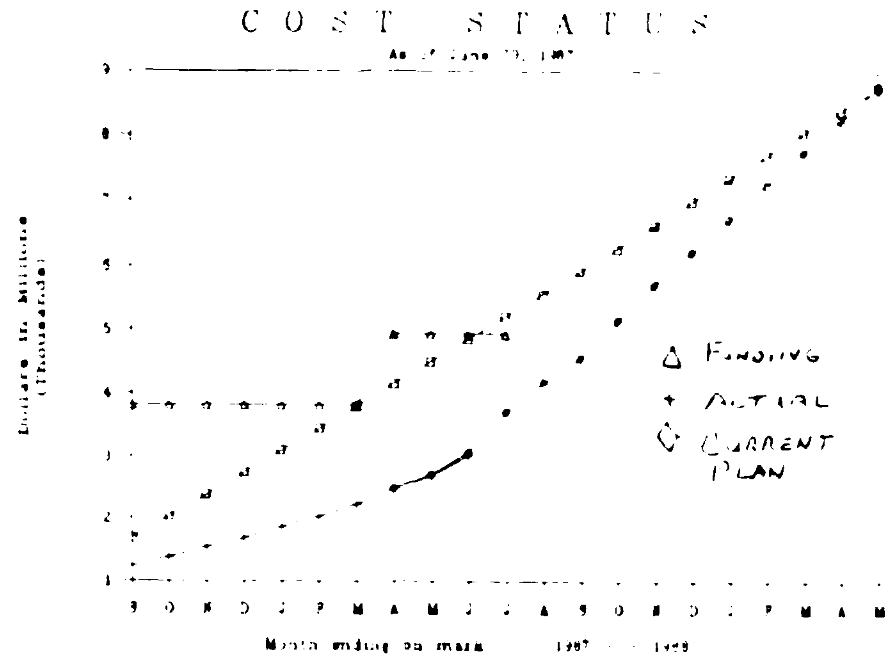
The following chart provides the final estimated costs for the second contract award after audit and negotiation:

PRICE BREAKDOWN

DESCRIPTION	TOTAL
Labor Hours	40,052
Labor Dollars	$ 891,783
Overhead	1,302,025
G & A	361,712
Material	583,236
Purchased Services	6,000
Subcontracts	102,968
Procurement Burden	22,150
Travel	31,657
Subtotal	$3,301,531
Cost of Money	91,089
Total Cost	$3,392,620
FEE	192,843
CPFF	$3,585,463

G. ACTUAL COST DATA

The level of funding, actual expenditure level and planned spending as of June 30, 1987 is illustrated graphically on the following page:



Actual cost data were obtained from Mr. [illegible] Dorsett, LMSC's contract administrator for the ANGAS project. The source of the following spending data [illegible] the Weekly Project Financial Status Report, dated September 31, 1986, which reflects spending at the [illegible] of the first contract phase.

ACTUAL COSTS
FIRST CONTRACT PHASE

	EXPENDED TO DATE	BUDGET
LABOR HOURS	17,424 hours	13,900
LABOR COSTS	$ 369,323	$ 302,46[illegible]
OVERHEAD	$ 556,858	$ 510,[illegible]
G & A EXPENSES	$ 184,323	$ 14[illegible],[illegible]
OVERTIME PREMIUM	$ 24	$ [illegible]
MATERIAL	$ 15,533	$ 110,[illegible]
PURCHASED SERVICES	$ 36,099	$ [illegible]
SUBCONTRACT	$ 0	$ 146,[illegible]
PROCUREMENT BURDEN	$ 1,6[illegible]8	$ 9,[illegible]
TRAVEL	$ 6,65[illegible]	$ 1[illegible],[illegible]
GRAND TOTAL	$ 1,1[illegible]0,515	$ 1,[illegible]

The difference between the amount funded under the contract and the budgeted total shown above is the cost of money and fixed fee amounts.

TOTAL FUNDED ($1,350,000) = TOTAL BUDGETED ($1,243,205) + COST OF MONEY ($38,450) + FIXED FEE ($68,345).

Chapter IV discusses the actual "budgeted" accomplishment and measure of technological progress for the first and second phases of the contract.

The following cumulative actual costs as of September 31, 1987, provide actual expenditures for the first and second contract phases.

ACTUAL COST
FIRST AND SECOND PHASES

	EXPENDED TO DATE	BUDGET
LABOR HOURS	55,585 hours	73,653
LABOR COSTS	$ 1,170,014	$ 1,369,867
OVERHEAD	$ 1,806,416	$ 2,023,831
G & A EXPENSES	$ 542,392	$ 705,570
OVERTIME PREMIUM	$ 118	$ 100
MATERIAL	$ 360,671	$ 196,203
PURCHASED SERVICES	$ 59,110	$ 61,100
SUBCONTRACT	$ 0	$ 146,700
PROCUREMENT BURDEN	$ 13,116	$ 12,380
TRAVEL	$ 25,606	$ 18,064
OTHER	$ 325	$ 125
GRAND TOTAL	$ 3,977,768	$ 4,533,950

The difference between the amount funded under the first and second contract phases and the budgeted total shown above is the cost of money and fixed fee amounts.

TOTAL FUNDED ($4,935,463) = TOTAL BUDGETED ($4,533,950) + COST OF MONEY ($140,325) + FIXED FEE ($261,188).

H. INFORMATION FROM THE GOVERNMENT'S PROGRAM MANAGER

The following discussion is based on a telephone conversation with LTCOL G. Lasche, USA, the ANGAS program manager on September 3, 1987. LMSC initially

proposed the ANGAS project to the government. At the time, Lockheed had recently completed the four million dollar Winkler project. Winkler was a scaled down aircraft-borne spectrometer that utilized many of the advanced technologies that were to be used in the ANGAS project.

Winkler was successfully developed, tested and flown at the estimated costs. LMSC's proposed costs for ANGAS were evaluated using Winkler's historical cost data.

ANGAS' technology was more advanced than Winkler's because it is designed to function in space rather than the earth's atmosphere. According to the program manager, projects like ANGAS that incrementally advance the SOA are usually completed much closer to the scheduled time and budgeted costs than projects that attempt quantum leaps.

The incremental funding of the ANGAS contract allows a structured development and technological evaluation at key development steps. LTCOL. Lasche, USA, stated the contract's SOW items and required tests stipulated in each contract phase provide the primary evaluation criteria to measure technological progress. To date all SOW items and tests have been satisfactorily completed on time.

It was also noted that labor costs are usually the most significant expense during the research and development phases of an SOA extension project.

IV. DATA ANALYSIS

A. INTRODUCTION

This Chapter analyzes the data presented in Chapter III. The analysis examines cost variances, schedule variances and the measurement of technological progress. Significant characteristics of Lockheed's cost estimating methods and models that are potentially useful in aiding better estimation of SOA extensions by the government will also be discussed. The contributions and role of the government's program manager for the ANGAS will also be highlighted when applicable.

B. COST VARIANCE ANALYSIS

Table 1 provides the dollar value and the percentage of cost variances by cost element for the first funding period of the ANGAS project as of 31 September 1986:

TABLE 1

COST VARIANCES

COST ELEMENT	ACTUAL COSTS	BUDGETED COSTS	COST VARIANCE	VARIANCE AS % OF BUDGET
LABOR	$ 369,323	$ 302,464	$ -66,859	22.10 %
OVERHEAD	556,858	510,392	-46,466	9.10
G & A	184,323	147,780	-36,543	24.73
OVERTIME	24	0	- 24	NA
MATERIAL	15,533	110,793	+95,260	85.98
PUR. SERV.	36,099	0	+36,099	NA
SUBCONTRACT	0	146,700	+146,700	100
PRO.BURD.	1,678	9,012	+ 7,334	81.38
TRAVEL	6,657	16,064	+ 9,407	58.55
TOTAL	$1,170,515	$1,243,205	+$72,690	5.8%

Table 1 indicates that negative cost variances[5] during the first funding phase of the ANGAS contract were realized in labor costs, overhead, G & A expenses and overtime premiums. These cost elements are influenced by labor costs either directly or through an applied rate ' › a direct labor base.

LMSC had budgeted for 13,900 labor hours. The number of labor hours actually expended during the first phase of the contract was 17,424 hours. Dr. George Nakano, LMSC's Principle Investigator for the ANGAS program, explained that during the early stages of development additional research and development effort was put into the solid-cryogen cooler system. This was a critical item in the overall SOA extension effort that has a long lead-time and would be built outside the Space Sciences Laboratory Division.

All other cost elements experience positive cost variances during the initial funding. A cumulative positive cost variance of $72.690, 5.8 % of budgeted total costs was reported at the conclusion of the first contract period.

Budgeted labor costs, overhead, G & A expenses and overtime premiums, all based on direct labor costs, were budgeted at 77.27 % of total budget costs. Actual costs for these cost elements accounted for 94.87 % of actual total costs.

Table 2 provides the cumulative and percentage variances for the first and second contract phases as of 31 September 1987:

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4 Negative cost variances result when actual costs exceed budgeted costs.

TABLE 2

CUMULATIVE COST VARIANCES

COST ELEMENT	ACTUAL COSTS	BUDGETED COSTS	COST VARIANCE	VARIANCE AS % OF BUDGET
LABOR	$1,170,014	$1,369,867	+$199,853	14.59%
OVERHEAD	1,806,416	$2,023,831	+217,415	10.75
G & A	542,392	705,570	+163,178	23.13
OVERTIME	118	100	- 18	18
MATERIAL	360,671	196,203	-164,468	83.82
PUR.SER.	59,110	61,110	+ 2,000	3.2
SUBCONT.	0	146,700	+146,700	100
PRO.BURD.	13,116	12,380	- 736	5.9
TRAVEL	25,606	18,064	- 7,542	41.75
OTHER	325	125	- 200	160
TOTAL	$3,977,768	$4,533,950	+566,182	12.26%

Table 2 indicates that negative cost variances existed at the end of the second funding phase in materials, procurement burden, travel and other, cost element catagories. A cumulative positive cost variance of $556,182, 12.263 percent of budgeted total costs, was reported at the conclusion of the first two contract periods.

LMSC had budgeted for 73,653 labor hours at this state of the development effort. The cumulative number of labor hours actually expended during the first two contract phases was 55,585 hours.

Direct labor and direct labor-based costs were budgeted at 90.4 % of total budgeted costs. Actual labor-related costs were 88.4 % of actual total costs.

Total actual costs for the ANGAS project have been slightly less than budgeted. Dr. Nakano and Mr. Dorsett, of LMSC, explained that the slightly slower overall spending rate was partially attributed to the uncertainties and delays experienced in obtaining timely approval of incremental funding requests. Material procurement and research efforts that are needed for SOW items defined in future phases of the project would have been initiated in the first and second phases of the project if future funding had been

approved. The incremental funding approach adopted by the government provides control over the project but also makes the development more difficult for the contractor.

Incentives and definite evaluation periods for a level of effort contract like the ANGAS project are established through the incremental funding, establishment of SOW goals for each contract phase and the ability to adjust future funding based on an evaluation of past performance and future potential.

The contractor has been provided incentive to satisfactorily achieve stated SOW goals for the phase of the contract for which funding has been reviewed.

Future long lead-time items required in later contract phases of the ANGAS project cannot be initiated until funding of those contract phases is approved.

C. SCHEDULE VARIANCE AND TECHNOLOGICAL PROGRESS

Schedule variances provide a way to highlight situations where effort is behind or ahead of schedule. The traditional methodology for analyzing schedule variances compares the budgeted cost of work performed and the budgeted cost of work scheduled. In a level of effort development contract, such as the ANGAS project, a determination of the budgeted cost of work performed becomes almost impossible to calculate due to the intangible nature of the goals and SOW items. An evaluation of technical progress is a more useful measure when used with the project's cost variances to evaluate overall benefits and project status.

> Analysis of technical variance is probably the most crucial type of analysis involved in the management process. It is the one where assistance of other technical experts may be required. It may also require some restructuring of the program merely to determine the cause of the variance. Note that any

significant technical variance will always result in cost and schedule variances. [REF. 2:p. 4-20]

Since no significant cost or schedule variances have occurred in the ANGAS project, the most obvious indicators of unsatisfactory technical progress are not evident. LMSC has satisfactorily completed all SOW items listed in the first and second phases of the contract. To further analyze technical progress, the ANGAS project's system engineering will be examined.

MIL-STD 449 defines system engineering as:

> the application of scientific and engineering efforts to: transform an operational need into a description of system performance parameters and a system configuration through the use of an incentive process of definitions, synthesis, analysis, design, test and evaluation; integrate related technical parameters and assure compatibility of all physical, functional and program interfaces in a manner which optimizes the total system definition and design,; integrate reliability, maintainability, safety, survivability, human and other such factors into the total engineering effort.

The contract SOW specifies the minimum technical requirements in the contract. Appendix B contains copies of the first and second contract phase Statements of Work. Examination of these specifications reveals that they are composed of specific configuration, design, performance and reliability and maintainability requirements. The program manager, LTCOL G. Lasche, USA, stressed that the lessons learned in the development of the Winkler project, which used similar technology, was a basis for the technical requirements developed for ANGAS. ANGAS system engineering appears to be a detailed specification of valid technical goals developed from past experience and an overall knowledge of the technologies involved.

It is logical that any analysis of technological progress be based on status reviews of system

engineering goals. The government's acquisition process requires formal and informal design reviews to:

> determine the adequacy of contractor and DOD in-house efforts towards achieving design goals. Participants should include design attribute specialists in reliability, maintainability, safety, and, particularly, logistic supportability. Reviews should include a preliminary design review, a critical design review (CDR), a design certification review, a functional configuration audit, a physical configuration audit, and a first-article configuration inspection. [REF. 2:p. 4-49]

The most recent formal review of the ANGAS project was the CDR which was presented to DARPA on July 21 and 22 of 1987.

> The CDR, a formal review of the detailed design of a configuration item, is performed by the program manager late in the prototype subphase when the design detail is essentially complete, but prior to drawing-release and fabrication of formal test articles. [REF. 2:p. 4-49]

The critical design review demonstrated that technical and system engineering goals for the ANGAS project were accomplished satisfactorily. The CDR specifically addressed:

1. System Engineering
2. Germanium Detector Subsystem Development (a critical technical component of the ANGAS system)
3. Shield Design (a critical technical component of the ANGAS system)
4. Mechanical Engineering specifications
5. Electrical Subsystem specifications
6. Source Deployment Subsystems
7. Cooler Subsystem specifications (a critical technical component of the ANGAS system)
8. Electrical Ground Support Equipment specifications
9. Monitor Subsystem specifications
10. Instrument Test Plan
11. Reliability, Quality and Safety
12. Instrument Development

In summary, ANGAS technical goals and objectives have been accurately detailed and specified as contract

requirements based on past experience obtained from the development of systems using similar technologies. Formal and informal reviews and evaluations of technical requirements have proved that the ANGAS project's technical goals are both viable and capable of being accomplished.

This research effort does not attempt to define a quantitative measurement technique for evaluating technical variance and accomplishment. An understanding of the long-range R & D planning steps developed by Ward D. Lowe and presented in Chapter III is a useful guide in establishing initial technical objectives for a proposed SOA extension project.

The prior development of the Winkler Program reduced the risks and development and provided technical information on some of the new technologies used in ANGAS. The following brief description of the relatively simple multi-attribute utility method, summarized for the <u>Navy Program Manager's Guide</u>, provides an avenue for future study of quantification of technical goals and measurement.

The model addresses the management of risk that is inherent in decision making with incomplete information. Establishing SOA extension technological objectives and measurement specifications at the initiation of a project is often based on incomplete information. The use of this limited information can be optimized through a five step process which consists of:

1. Breaking down the tasks to be accomplished into manageable components or attributes.

2. Estimating the utility factor, the relative importance of each component or attribute.

3. Developing a utility function or curve which describes the utility values as a function of some descriptive variable (i.e., reliability in terms of mean time between failure.)

4. Estimating the risks associated with attaining the utility values chosen for each attribute.

5. Developing options to avoid or overcome obstacles to success and to compare alternative paths, solutions, or concepts.

D. SIGNIFICANT CHARACTERISTICS OF LOCKHEED'S COST ESTIMATING METHODS AND MODELS THAT CAN AID GOVERNMENT COST ESTIMATING

Lockheed sometimes uses bottom-up cost estimating which is usually based on historical data and provides a high degree of accuracy. Cost estimating and evaluation within DOD should utilize historical costs, for completed projects that are similar in scale and technology, to evaluate projects under consideration.

Use of parametric cost models, specifically the RCA PRICE Hardware model is used by Lockheed during the early development and concept exploration phases when historical cost data does not exist. Parametric cost models, which allows economic SOA extension trade-off and schedule analysis, should be used by DOD when historical data does not exist early in development stages.

The Lockheed internally developed STAR model combines the characteristics of a similar-to-model and an associated model. This model, which was described in detail in Chapter II, is based on a historical database that has been developed over a 20 year period. The data base represents actual production and development cost experience, which can be retrieved by line item or box level based on relatively simple input characteristics. Development of similar integrated data base and models within DOD or major components would significantly enhance the government's ability to accurately estimate SOA extension costs.

V. CONCLUSIONS

The conclusions drawn from this research effort are based on the data and analysis of the ANGAS project. These conclusions can be used as a basis for future studies involving SOA extension cost estimating methods and case studies.

Primary Research Question: **How do estimated development and production costs compare with actual costs for the ANGAS project?**

Development costs were the primary costs estimated and recorded to date due to the early stage of development of the ANGAS project. Total actual costs were slightly lower than total budgeted costs. Direct labor and labor related costs were higher than budgeted during the first phase of development. Variances did exist within individual cost elements. No cost element experienced negative cost variances during both contract phases that were evaluated with the exception of a $24 and $18 cost overrun in overtime premiums.

Subsidiary Research Questions:

1. **What methods and techniques were used to estimate development costs?**

LMSC used a bottom-up, engineering cost estimating methodology to estimate development costs. These estimates were generated within the Lockheed Space Sciences Laboratory based on past experience of costs incurred developing similar satellite borne systems. The bottom-up estimating methodology used at LMSC provided detailed functional and cost element estimates based on historical cost data and specific contractual requirements as detailed in the WBS, SOW and RFP.

2. **How was technological progress measured and evaluated?**

Technological progress was measured and evaluated by monitoring completion of the specific configuration, design, performance and reliability and maintainability requirements stated in the ANGAS Statements of Work during the formal and informal project reviews. The program manager for ANGAS was able to state technical goals and objectives based on experience gained from the development of a similar spectrometer system that used many of the same advanced technologies.

3. **What factors helped or hindered accurate cost estimating and accomplishment of stated SOA extension goals?**

Accurate cost estimating was enhanced by the existence of historical data on similar type SOA extension development costs. The division of LMSC that was developing the ANGAS project was also experienced in developing similar systems. ANGAS incrementally extended the SOA based on a smaller scale project that combined many of the same technologies but was designed to function in the earth's atmosphere instead of outer space. Historical cost data, technical experience and incremental SOA extension enhanced cost estimating accuracy and accomplishment of technological goals.

Factors that hinder accurate cost estimating and accomplishment of stated SOA extension goals arise from the inherent risks of decision making with incomplete information. The inability for the government to accurately specify project design and specification requirements and monitor accomplishment through formal and informal reviews greatly hinders accomplishment and measurement of stated SOA extension goals. Lack of

historical data, technical experience and inability to correctly interpret contract requirements hinders contractors from correctly estimating SOA extension costs.

Findings: There were no significant variances between total estimated and total actual costs to date. Due to the contractor uncertainties associated with the incremental funding used in the project the spending rate was slightly lower than planned.

Incremental funding of a DOD SOA extension project definite contract phases and the opportunity to specify and evaluate technological objectives during each phase. This type of funding provides incentives for the contractor to successfully achieve technological objectives to receive funding for later phases. Incremental funding provides leverage and flexibility to the government in reducing cost overruns and achieving technological goals. The length of time required for the development effort is increased with incremental funding.

Direct labor costs and costs applied as a percentage of direct labor costs were the most significant costs during the development phases. These costs accounted for over 75 percent of total costs in each phase.

SOA extensions that incrementally advance the SOA reduce the risk of costs overruns and failure to achieve technological goals. The historical cost data and expertise obtained through the development of the smaller scale Winkler project enabled DARPA to accurately detail system engineering specifications and technical test parameters.

The measurement and analysis of cost variances and technological progress is the primary gauge of

effectiveness for a research and development effort administered by a level of effort contract. Technical progress for the ANGAS project was evaluated as satisfactory.

Currently available parametric, analogous and similar-to cost estimating models used by LMSC and private industry could be adopted to a greater degree by the DOD to enhance SOA cost estimating accuracy.

Recommendations for Further Study: Additional case studies are needed to identify trends in the cost estimating techniques and accuracy of SOA extension efforts. The computer based cost estimating models that are discussed in this research effort and many other computer based models not addressed in this project merit a great deal of additional study. Identifying cost estimating methods that will allow the most efficient use of limited DOD funding by cost effectively including new technologies in SOA extensions and new system development are vital national objectives.

APPENDIX A

DEFINITIONS

Bottom-Up Cost Estimation Model: A Cost estimating procedure based on detailed functional and cost element estimates prepared at the lowest practical level of task and design detail.

Budget: Estimated costs of the effort defined in the work packages and level of effort SOW items. These costs should be broken out at the cost account level. The estimated cost of the effort scheduled to be accomplished at a point in time within DOD is termed "Budgeted Cost of Work Scheduled" (BCWS).

Critical Design Review (CDR): A formal review of the detailed design of a configuration item is performed by the program manager late in the prototype subphase when the design detail is essentially complete but prior to drawing release and fabrication of formal test articles.

Development Costs: Costs associated with research, planning and design for a new product or process or for a significant improvement to an existing product or process. Includes the conceptual formulation, design, and testing of product alternatives and construction of prototypes.

Intra-Lockheed Work Transfer (IWT) Items: Material items that are made at Lockheed and transferred at cost to another entity within the company. Includes a separate breakdown by cost.

Parametric Modeling: Cost estimating procedure which utilizes a model comprised of algorithms and mathematic equations. Estimated costs are derived from relationships of cost to physical or performance characteristics.

Purchased Items: Includes material items not considered standard commercial items or raw materials.

Raw Materials: Materials in a form or state that require further processing.

Standard Commercial Items: Consists of items that the contractor normally fabricates, in whole or in part, and that are generally stocked inventory.

State of the Art (SOA) Extensions: Used in this thesis to describe a new weapon system or component that has incorporated an advancement in technology in a unique process or for a unique application.

WBS Dictionary: The WBS dictionary defines each WBS element and describes the technical/functional task content and responsibilities.

Work Break Down Structure: A product-oriented family tree composed of hardware, services and data which results from project engineering effort during the development and production of a defense material item and which completely defines the project / program.

APPENDIX B

STATEMENT OF WORK
FIRST CONTRACT

1. The work and services to be performed hereunder shall be subject to the requirements and standards contained in Exhibit A and the following paragraph(s).

2. The Contractor shall carry out a program of research in advanced gamma-ray detectors for use in space which shall include the following tasks:

1. Conduct gamma-ray imaging studies,
2. Establish instrument GSE requirements,
3. Conduct preliminary design of germanium sensor and anticoincidence shield,
4. Prepare digital signal processing system requirements and specifications,
5. Prepare cryogenic cooling system specifications,
6. Conduct preliminary design of collimator, wheel, onboard hardware, germanium sensor electronics, and antishield housing and electronics,
7. Prepare germanium sensor procurement specifications and antishield crystal procurement specifications,
8. Complete final cooler design and performance simulation.

STATEMENT OF WORK
SECOND CONTRACT PHASE

Under Modification P00001, the Contractor shall conduct the final design and sensor/shield evaluation of a space demonstration experiment known as the DARPA-201 ANGAS Experiment aboard a free-flyer satellite mission. The work shall include the following tasks:

(1) Finalize design of a high sensitivity, fine energy resolution imaging spectrometer, known as the ANGAS instrument, background monitors and auxiliary equipment.

(2) Perform laboratory evaluations and bench tests of the Ge sensor design and of the NaI shield system.

(3) Conduct design studies, computer simulations and laboratory bench tests for performance verification of the imaging techniques to be employed on the ANGAS and finalize the design of the collimator mask system for the flight instrument.

(4) Provide the electrical, thermal, and environmental specifications and other interface information necessary to integrate the DARPA-201 payload aboard the satellite.

(5) Provide all physical, procedural, functional, and safety data necessary to generate an Experiment Requirements Document (ERD) consisting of:

(a) Interface Control Document.
(b) Ground Operations Requirements Document.
(c) Flight Operations Requirements Document.

(6) Provide the inputs necessary to meet the identified DARPA-201 milestone schedules. Departures from these schedules must be mutually agreed to by DARPA and the LPARL.

(7) Maintain an experiment quality program during the design and development of the payload.

(8) Design and initiate development of the ground support equipment (GSE) necessary to test and integrate the DARPA-201 payload with the free-flyer satellite.

(9) Provide DARPA-201 progress and status information and support the mission working group and status reviews as necessary.

STATEMENT OF WORK
PROPOSED 16.5 MILLION DOLLAR COMPLETION CONTRACT

The Lockheed Missiles and Space Company will provide to the Defense Advanced Research Agency and the Office of Naval Research the necessary personnel, equipment facilities and services to conduct a space demonstration experiment known as the DARPA-201 ANGAS Experiment aboard a free-flyer satellite mission. In the conduct of this work the following tasks will be performed:

1) Design, develop, test and calibrate a high sensitivity, fine energy resolution imaging spectrometer, known as the ANGAS instrument and an auxiliary background monitor.

2) Conduct design studies, computer simulations and bench tests for performance evaluation of the imaging techniques for intended employment on the ANGAS collimator mask wheel.

3) Based on the timely receipt of the electrical, thermal and environmental specifications and other interface information from the Government, provide the necessary information to integrate the DARPA-201 payload aboard the satellite.

4) Provide all physical, procedural, functional and safety data necessary to generate an Experiment Requirements Document (ERD) consistent with the vehicle and interface requirements specified in the STP From 1721 (1985). The ERD consists of

a) Interface Control Document
b) Ground Operations Requirements Document
c) Flight Operations Requirements Document

5) Provide the inputs necessary to meet the identified DARPA-201 milestone schedules.

6) Flight qualify the DARPA-201 payload through the maintenance of an experiment quality program during the design and development of the payload. The Principal Investigator will have full responsibility for conducting all aspects of the quality program. The quality program practices with the ONR.

7) Provide the ground support equipment (GSE) necessary to test and integrate the DARPA-201 payload with the free-flyer satellite.

8) Provide logistics and operation support to the DARPA-201 payload during definition, integration , test and on-orbit operations.

9) Provide DARPA-201 progress and status information using the Lockheed R & D standard

management and accounting practices. Support the mission working group and status reviews as necessary.

10) Based on the timely receipt of government-furnished computer-compatible agency data tapes, analyze the first two years of on-orbit data.

11) Provide flight performance reports as required.

12) Submit the scientific results acquired with the DARPA-201 instruments for publication in the open technical literature.

MAJOR MILESTONES FOR THE

DARPA-201 ANGAS EXPERIMENT

Project Milestones 1985 1986 1987 1988 1989 1990 1991 1992

Harware Design------------

Procurement-------------------

ICD Signoff--------------

Ground Operations--------
required documentation

Flight Operations--------
required documentation

Hardware Development---------------

Instrument Test--------------------

Hardware Delivery------------------

Spacecraft Prelaunch Support------------

Launch---------------------------------------

Post Launch Operations---------------------------

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